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Department of Psychology

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ACCOMMODATION IN UNTEXTURED STIMULUS FIELDS

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INTRODUCTION

Recently, evidence has been accumulating on the state of accommodation when visual fields have reduced textural stimuli and when visual texture is absent. Although most commonly used refractive techniques are impractical for measuring accommodation under these circumstances, the laser optometer (Hennessy and Leibowitz, 1972; Leibowitz and Hennessy, 1975) has made such measurements a simple matter. Moreover, this technique has been demonstrated to be effective without interfering with the magnitude of the accommodation being measured (Hennessy and Leibowitz, 1970; Leibowitz and Owens, 1978).

The state of accommodation during conditions of reduced textural cue availability has both basic and applied implications. For example, Owens and Leibowitz (1975) have demonstrated that the commonly used fixation point in a dark field was a notably poor stimulus for accommodation. More complex targets viewed with a gradual reduction of the luminance show a progressive lowering of their ability to stimulate accommodation (Johnson, 1976). Certainly these conditions exist in many experimental situations but they also occur in many real-world situations.

The accuracy of accommodation to stimuli imbedded within poorly textured fields can be critical in many instances of vehicle operation. Night, fog, and empty visual fields during flight provide low texture situations. Target stimuli of interest within these fields may vary considerably in brightness, contrast and complexity. Likewise, age old phenomena such as the moon illusion have been found to be at least partially dependent upon the state of accommodation in the presence of a low texture stimulus field (Iavecchia, Iavecchia and Roscoe, 1978).

The classical view of the control of accommodation, first elaborated by Helmholtz (1867/1962), dictates that any accommodative response in the absence of patterned visual stimulation be viewed as maladaptive. This view embraces a single innervation theory of accommodation in which activation of the ciliary muscle can only relax the tension on the lens, increasing its curvature (and the accommodative power). The physiological resting position of accommodation is thus viewed as being at optical infinity. For this view to be correct an intermediate response would require the presence of a maladaptive active process.

Given the classical view, a puzzling and persistent problem in physiological optics has been the manifestation of inappropriate accommodation. The basic findings have been known for at least two centuries. Lord Maskelyne, the royal astronomer, reported that the use of a negative lens facilitated his night observation (Levene, 1965) and more recently Rayleigh (1883) noted that he was distinctly myopic in a darkened room. A related phenomenon, that has been more recently discussed with particular reference to high altitude aircraft flight, demonstrates a similar finding. Whiteside (1957) reported a distinct nearsightedness occurs when flying in a stimulus-free external field--Ganzfeld. Also when looking through microscopes, observers typically exhibit unnecessary increases in accommodation (Schober, Dehler, and Kassel, 1970).

When textural cues are reduced through lowered illumination and contrast, night and empty-field or space myopia occur. Instrument myopia is typically attributed to viewing through small apertures. These myopias are referred to as anomalous because, contrary to the classical view, accommodation for near images occurs in the absence of these images (Leibowitz and Owens, 1978). An alternative theory of accommodation proposes that there is dual control of the ciliary muscle and the intermediate state reflects a passive return to a neutral balance point between these opposing systems. Although this alternative theory has been frequently proposed and subsequently denied, anatomical and physiological evidence has mounted making it difficult to reject (see Cogan, 1937 for a review of the early evidence or Benel, Note 1 for an updated review).

Despite the large body of supporting evidence, the actual state of accommodation under these reduced cue viewing situations is not well known. Using the laser optometer, Leibowitz and Owens (1975) found that the near accommodative response in the dark for 124 college students was approximately 1.7 diopters (D), corresponding to a focal distance of 59 cm. All students had at least 20/25 far and near acuity. Only four had dark focus (accommodative responses in the dark) responses of 0.5 D or less. To be consistent with the classical view, it would be expected that the majority would have had responses corresponding to a value at or near optical infinity. Control experiments by Leibowitz and Owens had excluded the possibility that pupillary diameter changes were responsible.

The empirical validity of the dark focus appears to be quite robust. Leibowitz and Owens (1978) replicated their earlier findings reporting a mean response of 1.5 D for 221 subjects. Miller (1978) and Benel and Benel (Note 2) have shown similar results, although reporting actual dark focus values slightly in excess of those earlier studies. This disparity is not surprising in light of the marked dark focus variability reported by Leibowitz and Owens (1975; 1978). The earlier distribution had been shown to be essentially normal with a range from 0 - 4 D and a standard deviation of 0.72 D.

Much of the early evidence surrounding the anomalous myopias appeared equivocal. Mellerio (1966) reviewed this literature and reported that most of the arguments could be attributed to small data samples and the likelihood that individual differences created the disparity among the results of different laboratories. He also rejected the implication that chromatic aberration could be responsible for night myopia. A maximum of 0.4 D could be attributable to chromatic aberration, far less than the average amount of accommodation exhibited in darkened surroundings. Spherical aberration may also be eliminated as a primary cause. Ivanoff (cited by Mellerio, 1966) has shown the eye is aplanatic at about 1.5 D. Viewing through small pupils significantly reduces spherical aberration, but myopia remains (Hennessy, Iida, Shiina, and Leibowitz, 1975).

The state of accommodation in a bright empty field argues against both the chromatic and spherical aberrations as well. However, it would be plausible to propose that convergence occurs in the absence of visual stimulation and the loose linkage between convergence and accommodation creates the near accommodative response. Fincham (1962) did report fusional convergence to be stimulated by the presence of objects in the stimulus field, but in complete darkness convergence disappeared leaving the night myopia unchanged. In a bright field, Lukiesh and Moss (1940) had shown that myopia still exists in the absence of convergence. Whiteside (1957) reported that subjects accommodated close to optical infinity, immediately showed "involuntarily" increased accommodation when the stimulus for distant accommodation was removed. Whiteside also reported a range of values for this "myopia" to be 0.5 - 2.0 D.

In contrast to the previous myopias, instrument myopia occurs during observation of targets of high contrast and rich detail. Hennessy (1975) reviewed the literature and reported the apparent lack of relationship between a change of the visual stimulus and the accommodative response during observation through an optical instrument. A wide variety of variables have been manipulated with no apparent effect of the magnitude of instrument myopia. Hennessy tested three possible causes of instrument myopia: the influences of peripheral stimuli, the effect of perceived distance, and the intermediate resting state of accommodation.

Hennessy found that objects in the periphery can influence accommodation. Interestingly, a more distant surround can reduce accommodation to a central target. However, these changes are not large enough to produce instrument myopia. Perceived distance (e.g., apparent nearness of objects viewed through a microscope) has not been shown to have a reliable effect on accommodation. The mean refractive state while viewing through the microscope, was found to be 1.91 D (Hennessy, 1975). The relatively small exit pupil of the microscope (2 mm or less) increases the depth of focus of the eye, thereby reducing the need to accommodate allowing the eye to lapse toward its dark focus. Leibowitz, Hennessy, and Owens (1975) also describe this as allowing the observer to function with the level of accommodation that is most comfortable and/or permits the clearest image.

The majority of recent work using the laser optometer to measure the refractive state has been performed by Leibowitz and his students. Although the anomalous myopias have been known for sometime, only recently has the refractive state of eye in the dark been compared to the refractive state under the various myopias. Leibowitz and Owens (1975) have reported a high correspondence between the dark focus and the magnitude of the myopias. Pearson product moment correlations (r) for night, empty field, and instrument myopia were 0.84, 0.81, and 0.68 respectively. Despite the reliable correlation between the dark focus and each of these myopias, it is obvious that the accommodative response under the anomalous myopias does not exactly duplicate the dark focus.

For example, Figure 1 represents the scatter plots from Leibowitz and Owens (1975) for the magnitude of accommodation in the myopia-inducing conditions as a function of the dark focus. Accordingly, if the anomalous myopias were merely a manifestation of the dark focus, the data would fall on the diagonal line. For both night and empty field myopia the majority of points are below the line, indicating relatively lower accommodation. Indications are that instrument myopia produces relatively higher accommodation. An analysis of variance (ANOVA) of the original data (courtesy of D.A. Owens) revealed that statistically reliable differences existed among the means for

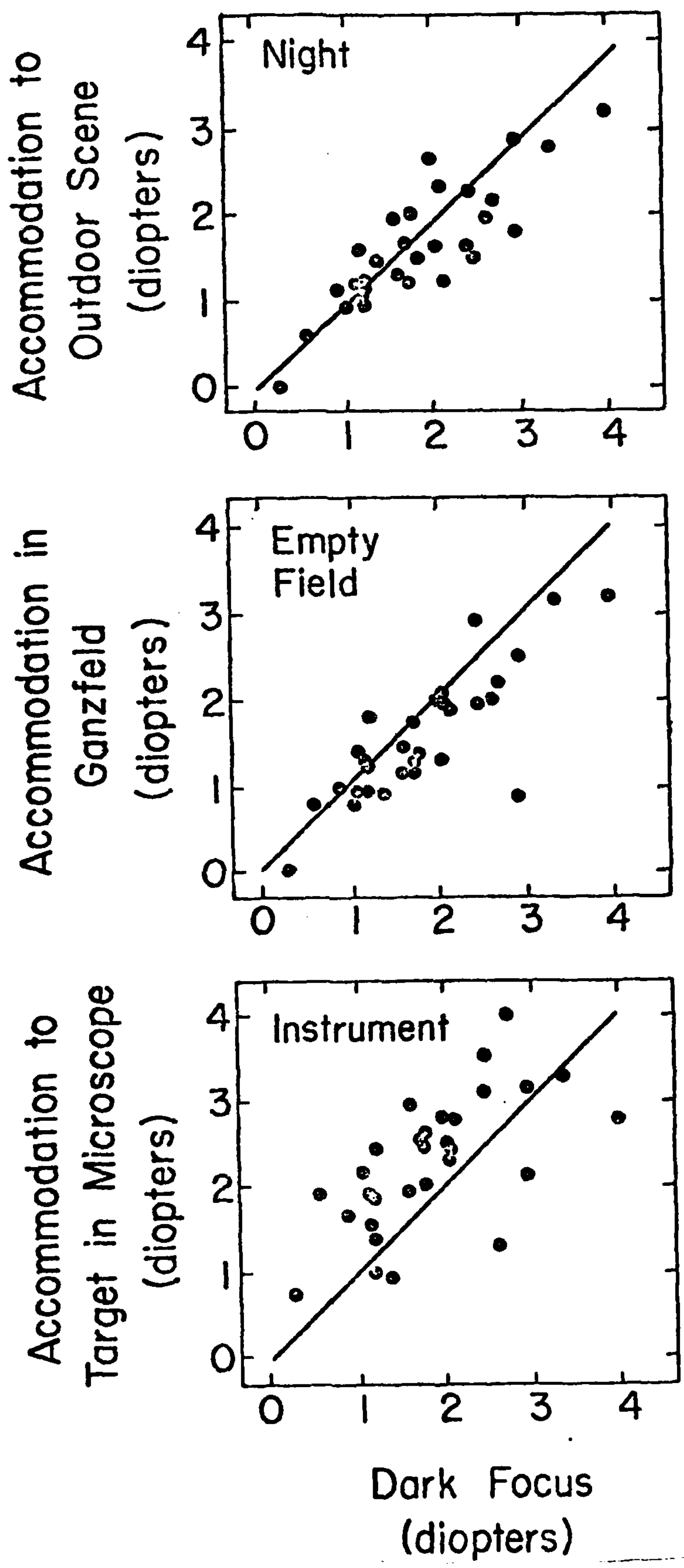

Figure 1. Magnitudes of night, empty field, and instrument myopia as a function of the dark focus. Each point represents a datum for an individual observer in all three situations. (After Leibowitz and Owens, 1975).

the four conditions: $\underline{F}(3,93) = 29.71$, $\underline{p} < .0001$. Newman-Keuls post-hoc comparisons revealed that all means differed reliably ($\underline{p} < .05$, corrected for number of comparisons) except that empty field and night myopia did not differ from each other.

The reliable departures from the intermediate resting position (exemplified by the dark focus) in no way negate the importance of the dark focus in determining the ultimate response of the accommodative system under these conditions. The reliability of these departures does raise several questions. The first concerns the role that mere illumination plays in determining the accommodative response when textured stimuli are poorly represented or absent. In all cases the anomalous myopias are expressed in lighted conditions, although, with the exception of empty field myopia, frequently attenuated. It also raises a question of the effects of instructions in the final accommodative response.

For the two myopias (night and empty field) exhibiting an outward shift from the dark focus, luminance was obviously greater than 0 cd/m^2. It was also in these two conditions that observers received explicit instructions most similar to those received for measuring the dark focus. Generally, observers were instructed to relax (personal communication with D.A. Owens). Although it would be possible for observers to interpret these instructions differently under differing conditions, it seems plausible to conclude that most observers would comply with the explicit instructions.

On the other hand, the instrument myopia conditions explicitly require observers to focus a square wave grating viewed through the 2 mm exit pupil and the luminance of 11.0 cd/m^2 is in the photopic range. Previous research under reduced textural cues had shown accommodation to draw nearer even when observers were explicitly urged to locate distant targets (Whiteside, 1957). In this case pilots in aircraft found they had unwittingly accommodated (and converged) on specks on the windscreen.

METHOD

To investigate the effects of illumination and instructions on the accommodative response to stimuli presented in untextured stimulus fields, a series of experiments was conducted in which accommodative responses were collected to various stimulus conditions. In contrast with procedures used by previous investigators of the night and empty field myopias, observers in all cases were explicitly instructed to focus the stimulus in question. This latter instruction was intended to simulate one aspect of the instrument myopia condition, although the presently used targets were never as well textured as the square-wave gratings used by Hennessy (1975) and by Leibowitz and Owens (1975).

Apparatus

Two separate pieces of apparatus were interfaced for the experiments. A modified version of the Hennessy and Leibowitz (1972) laser optometer (see Figure 2) was designed to be functionally equivalent to but more compact and portable than the original. The beam of the 2.0 mW He-Ne laser was diverged, collimated, and then reflected from the surface of a slowly rotating drum. The resulting elliptical speckle pattern was superposed on the subject's field view by means of a beam splitter. The intensity of the speckle pattern was adjusted by a pair of crosspolarized filters until only the brightest speckles remained visible. The exposure duration (.75 sec) was controlled by a shutter.

The test pattern speckles indicate the observer's refractive state. If the observer is overaccommodated (relatively myopic) for the test pattern, the speckles will appear to "flow" with the drum's rotation; if underaccommodated (relatively hyperopic), they appear to "flow" in the direction opposite the drum's rotation. When accommodation places the "plane of stationarity" (Charman, 1974) conjugate with the retina, the speckles will appear

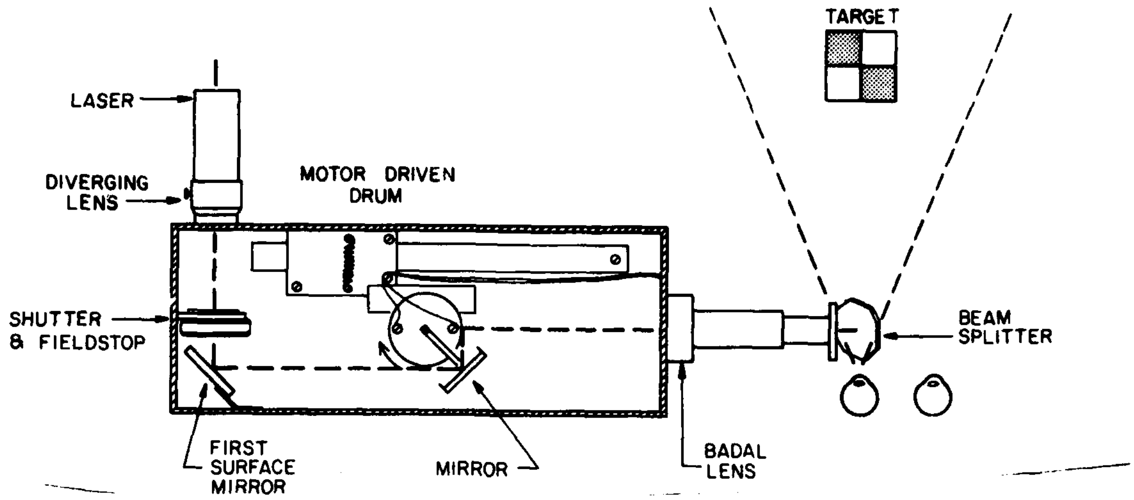

Figure 2. Cut-away schematic of the modified laser optometer.

stationary or merely swirling but not to "flow" in either direction. Bracketing movements are made with the drum until the plane of stationarity is located. The resulting optical distance is read from a scale.

The second piece of apparatus was an enclosed stimulus presentation box. This box was functionally similar to the apparatus used by Kaufman and Rock (1962); it provided a simulated "moon" that could be combined optically with an external scene and a variable-diameter comparison disc at one meter. Figure 3 is a cutaway schematic showing the apparatus arranged for viewing the collimated virtual image of a lighted disc or "moon." The collimated light is reflected from a combining glass. Figure 4 shows the positioning of a first-surface mirror to occlude the virtual image and reflect the image of the comparison disc. By inserting an iris diaphragm and frosted glass into the aperture immediately below the mirror, a third lighted disc may be presented at a distance of 0.25 m. Each disc subtends an angle of 0.67° at the eye and has a luminance of approximately 5.4 ft. L.

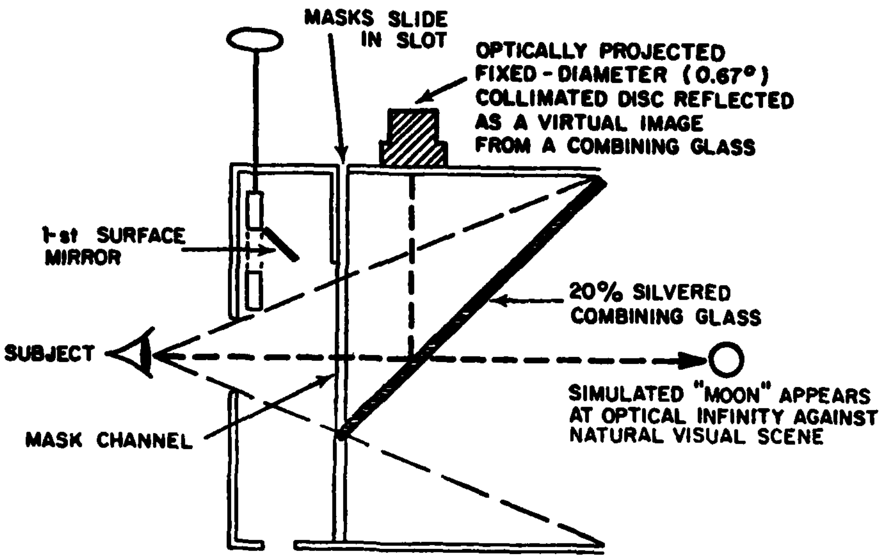

Figure 3. Cut-away schematic of the stimulus presentation box. Trans-illuminated, collimated lighted disc (0.67°) provides stimulus as virtual image projected from optical infinity.

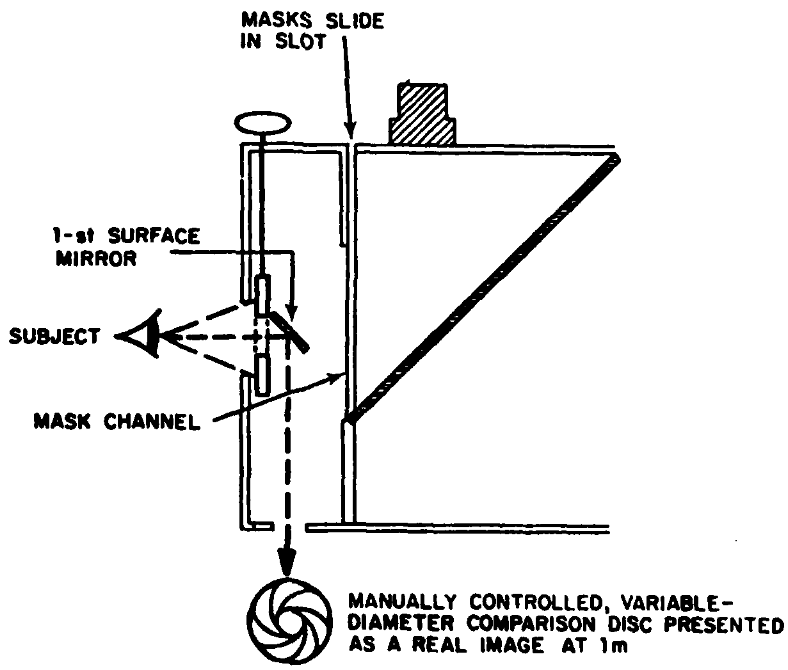

Figure 4. Cut-away schematic of the stimulus presentation box. First surface mirror reflects transilluminated lighted disc (fixed at 0.67°) from one meter projection distance.

This apparatus also incorporates an adjustable chin and forehead rest to position each subject properly to insure that viewing distances remain constant across subjects. Figure 5 indicates the external appearance of the stimulus presentation box. The laser optometer is shown mounted to the left and positioned such that the laser speckle pattern coincides with the optical axis of the lighted discs and eye. The subjects viewed all stimuli monocularly with the left eye, although the right eye remained uncovered in the darkness.

Procedure

All observers were briefed as to the general nature of the experiment. They were first screened for acuity with either a Snellen chart or with an Orthorater. Preliminary screening showed all observers to have a minimum of 20/25 near (Experiments II and III only) and far acuity. If necessary those observers requiring corrective lenses wore them during the course of the data collection procedure. It was unlikely that any significant uncorrected myopia existed in any observer.

All other measurements were conducted in a darkened room that was essentially light tight. Observers viewed all stimuli in a dark surround. Each observer was given sufficient training to develop familiarity with the laser speckle pattern and the required responses. Observers were instructed to respond vocally with either up, down, or stationary responses. If the observer requested, a given position of the drum was exposed again. Observers were never informed as to the actual position of the drum during measurements or the distances of the lighted discs.

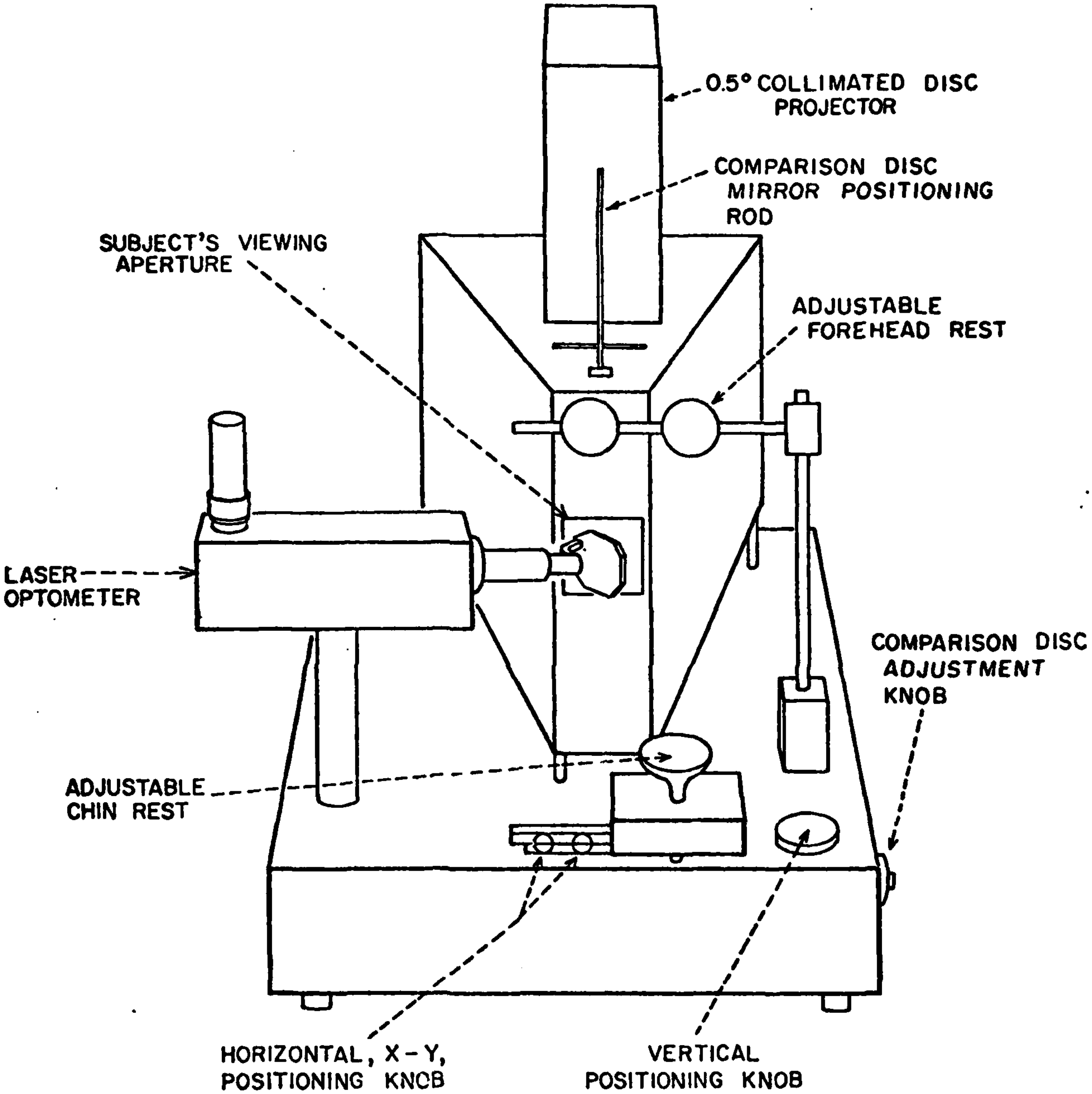

Figure 5. Perspective drawing of the stimulus presentation box with the laser optometer in place.

EXPERIMENT I

Subjects

All 10 participants in this study were Psychology graduate students at the University of Illinois at Urbana-Champaign. They were selected on the basis of availability, willingness to perform, and reported uncorrected distant acuity of 20/20 (verified by Snellen chart). Near acuity was not checked, but it seems reasonable to conclude that any near acuity visual problems would be noticed by those who read as much as graduate students.

Procedure

This experiment employed the collimated and 1.0 m uncollimated lighted discs that provided relatively untextured accommodative stimuli and sufficient illumination to avoid being below photopic levels. Accommodation was first measured for the dark focus and then for either the 1.0 m or the collimated disc with the order counterbalanced across subjects. The dark focus was again measured following data collection to verify the initial readings.

Results and Discussion

Consistent with the previously mentioned data of Leibowitz and Owens, it was found that accommodative responses to either of the two illuminated discs were more distant than those recorded in the dark. An ANOVA revealed that reliable differences existed among the means: $F(2,18) = 5.99$, $p < .01$. Also, the responses in the three situations were found to be highly correlated ($r > .80$).

In general, the results might suggest that accommodation responses in lighted environments are more distant than the accommodation response in the dark. In three cases the responses to the 1 m target were actually indicative of increased accommodation; however, for one observer, accommodation shifted from 1.0 D in the dark to 1.4 D in response to the 1 m disc. This shift represents a change from what would have been accurate accommodation to an inappropriate increase. The other two subjects who shifted inward had dark focuses beyond 1 m.

Clearly changes in accommodation did occur. The results do not conclusively indicate a shift from the dark focus toward more distant accommodation in general. They could be interpreted as representing a shift toward accurate accommodation with a large lag and low accuracy. At least one observer indicated a shift from the dark focus outward leaving him as far away (in diopters) from the 1.0 m target after the shift, but in the opposite direction. This could hardly be viewed as a shift toward more accurate accommodation. With the exception of one observer, all responses to the collimated disc were relatively more distant, although all shifts were less than 1.0 D in magnitude. This reliable outward movement still left the average observer accommodated only slightly beyond arm's length.

The interpretation of these results remains somewhat ambiguous. In most cases the lighted discs were projected from distances beyond the dark focus and an outward shift, albeit quite inaccurate, would not be surprising. Certainly the results show that accommodation is both grossly inaccurate while viewing lighted discs within a darkened surround and highly correlated with an individuals dark focus. However, these results might be parsimoniously explained by an inappropriate magnitude of accommodation.

EXPERIMENT II

Subjects

The Psychology 100 subject pool provided 14 observers for this experiment. All observers were screened to insure that the minimum near and far acuity requirements were met.

Procedure

The same general procedure used in Experiment I was followed. The third lighted disc at 0.25 m was added for this experiment. Accurate focus on this disc would require accommodation of 4.0 D, well within the dark focus distance of most observers. The order of presentation of lighted discs was counterbalanced across observers (although the counterbalancing was incomplete because the number of subjects did not allow three rotations through the order).

Results and Discussion

Once again, an ANOVA revealed reliable differences among the means, $F(3,39) = 23.72$; $p < .0001$. The mean dark focus recorded for the observers in this experiment was nearer than for the previous group, but the results for the dark focus, 1.0 m disc, and collimated disc paralleled those of the first experiment. Namely, the two lighted stimuli produced relatively more distant accommodation responses than the dark focus value. Viewing the 4.0 D disc produced a nearer mean accommodation response than the dark focus (3.27 D versus 2.67 D). Also, there was a high degree of correspondence among all conditions on the accommodative measure ($r \geq .8$ in each case).

Although accommodative shifts were in the correct direction for the majority of observers across conditions, there were sufficient departures to question the accuracy of accommodation for the targets used. All three target discs were presented in a completely dark surround providing a sharp edge between light and dark. Theoretically, the vergence of light and the resolvable edge contour could provide sufficient cues for accurate accommodation. Despite these cues and the explicit instructions to attend to and focus on the lighted discs, accommodation was relatively inaccurate. This inaccuracy was particularly notable for the collimated disc.

Accommodation for most subjects was generally most accurate to the disc projected from the distance nearest the dark focus. This is consistent with the findings of Owens (1978), but very little comfort can be drawn from this finding. As Johnson (1976) has noted, accommodation is most accurate to well lighted targets presented near the dark focus, and most observers in this group had relatively near dark focuses. Another potentially troublesome point for interpreting data lies with respect to illumination level. The equivalence of luminance among the stimuli makes it difficult to separate the effect of differing instructions in dark focus versus lighted conditions from the possible simple effect of luminance change.

EXPERIMENT III

Subjects

An additional 11 observers were recruited from the Psychology 100 subject pool and screened for visual acuity as in Experiment II.

Procedure

The same general procedure was followed as in Experiment II with two levels of illumination for the collimated disc, the normal level and a level well below photopic range (< .1 ft. L.).

Results and Discussion

An ANOVA revealed reliable differences among the five means, $\underline{F}(4,40) = 9.34$; $\underline{p} < .0001$. All means differed reliably from all others ($\underline{p} < .05$, corrected for number of comparisons). This particular group of observers had relatively distant dark focuses ($\bar{x} = 1.26$ D, and seven observers had dark focuses less than 1.0 D). With this group the dark focus was the most distant average response collected. The responses to all illuminated disc conditions were relatively more myopic, 1.36 D for the photopic collimated disc, 1.47 D for the 1.0 m (1.0 D) disc, 2.02 D for 0.25 m (4.0 D) disc, and 1.69 D for the reduced luminance collimated (0.0 D) disc.

For this particular group of observers, accommodative responses to the brighter collimated disc parallels the responses of the observers from Experiment II in terms of inaccuracy of accommodation. However, the relatively more accurate mean accommodation to this target for Experiment III compared to Experiment II merely reflects the relatively more distant dark focuses among the observers in Experiment III. Similarly, accommodation to the 1 D target was similar to the previous experiment, but more accurate accommodation in Experiment II reflected the relatively nearer mean dark focuses of those observers. Once again, accuracy of accommodation to low stimulus value targets appears more related to dark focus distance than actual target distance.

Although the accommodative responses in both the bright and dim conditions shown in Figure 6 are notably inaccurate, it can be seen that the responses of 10 of 11 observers are even less accurate while viewing the dim disc. The mean difference between conditions (0.33 D) is consistent with estimated amounts of night myopia attributable to chromatic aberration. For example, Wald and Griffin (1947) reported about 0.4 D of relative myopia to be related to the Purkinje shift of maximal visual sensitivity when changing from bright to dim light. This indicates at least a portion of the difference between the dark focus and the illuminated stimulus condition could be attributable to this effect.

GENERAL DISCUSSION

Returning to the original questions, the effect of luminance shifts for a given condition appears to be consistent with the findings of Wald and Griffin (1947). Namely, with a reduction in luminance there will be an increase of approximately 0.3 to 0.5 D accommodation when observers view distant targets. Presumably this effect accounts for the shifts noted in the data of Leibowitz and Owens (1975). Their findings indicated a mean shift of an approximately equivalent magnitude (0.3 D) when shifting from the lighted condition (night and empty field) to the dark focus.

Explicit instructions to focus on a target of low stimulus value (the lighted discs) had very little effect on the accuracy of accommodation. In several instances, increased accommodation over the dark focus was exhibited while viewing relatively more distant targets. Although this finding is

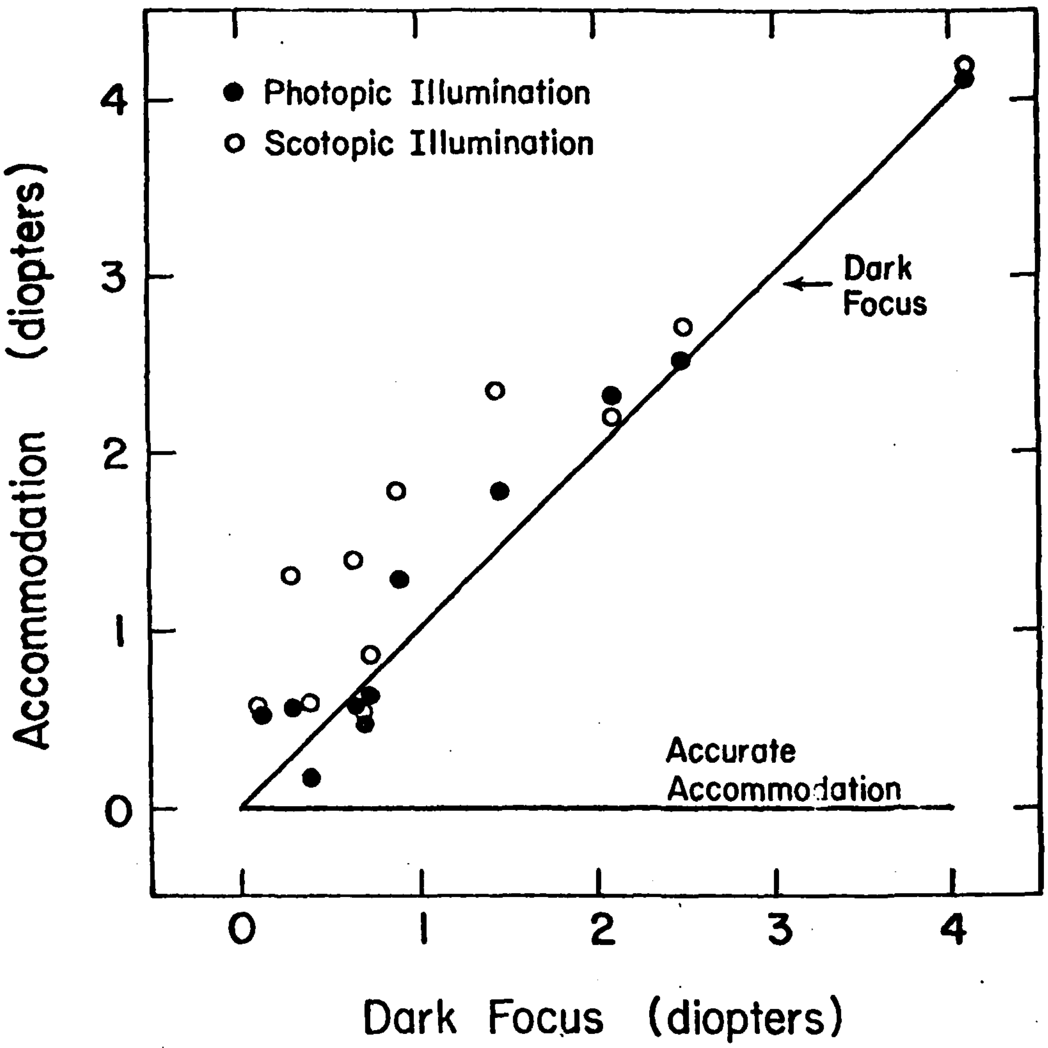

Figure 6. Accommodation to the collimated lighted disc with two luminance levels as a function of the dark focus.

suggestive of a tendency for at least some observers to become inappropriately myopic when instructed to focus, it is not definitive. Additional support for such an involuntary tendency toward myopia while attempting to focus more distant targets may be found in Whiteside (1957). Pilots attempting to locate distant targets in an otherwise bright, empty field found they had involuntarily accommodated to specks on the aircraft windscreen or canopy.

Subsequent research has shown this effect to be related to an involuntary tendency to focus the target at an intermediate distance when competing stimuli are at disparate distances (Mandelbaum, 1960). Owens (1976; 1978) has shown this tendency to be most strongly expressed when one target is at or near an observer's dark focus. Although the disruption of vision is involuntary, practice or strong subjective effort may overcome the effect. The strong subjective effort is presumably most effective when the desired stimulus is adequate for accommodation, in the Owens study, Snellen Es or grating targets.

It is unlikely that the finding of the relatively more myopic response in the instrument myopia condition of Leibowitz and Owens can be attributed to instructional set. The lack of generally inward shifts in the majority of subjects in the current study vitiates such an explanation. Moreover, the original data of Hennessy (1975) indicate nearly perfect correspondence on the average between the dark focus and the magnitude of instrument myopia (the regression line nearly passes through the origin with a slope of almost 1.0).

Certain aspects of the method of data collection may account for the relatively nearer responses reported in the Leibowitz and Owens instrument myopia condition. Hennessy found that the method of adjusting a microscope can lead to varying degrees of myopia. When adjusting the microscope until a clear image was seen from near to far versus from far to near the resulting myopia was found to vary by 0.44 D on the average. When oscillating adjustments were allowed the resulting average response was midway between the previous two methods. It is possible that methodological artifacts produced the apparent inward shift observed by Leibowitz and Owens.

The most striking finding from these experiments is the lack of accommodative accuracy. Figure 7 presents the data pooled across experiments for the various conditions. The data, in all cases, demonstrate that the accommodative response more nearly resembles the observers' dark focus than accurate accommodation. For those observers whose dark focus is near the target distance, accommodation is generally most accurate. Johnson (1976) had reported similar results using targets with greater texture available (sinusoidal gratings). The inaccuracy was exacerbated by lowered illumination with observers exhibiting fixed focus equal to the dark focus for all stimulus distances at the lowest illumination levels.

Analogously, low resolution targets presented in a darkened surround produce relatively little change from the dark focus despite explicit instructions to accommodate accurately. Figure 8 presents data from observers for the conditions common to Experiments II and III. An ANOVA for these data showed relatively small but reliable mean differences among these data: $F(3,72) = 26.12$, $p < .0001$. These data verify that accommodation does shift with changes in target distance, but the amount of the shift is extremely limited.

Toates (1972) proposes that the accommodative system acts as if it were a proportional controller. Figure 9 illustrates the effect of varying stimulus distance upon accommodation. According to Toates, the steady-state error observed in a number of studies reflects myopia for distant objects and hypermetropia for near. The amount of error is proportional to the optical or real distance of an object from a fixed reference. This fixed reference is also the reference for distance previously referred to. This point is the dark-focus value.

Although the empirical validity of Toates' proportional controller is sound, the current data strongly suggest a second aspect previously alluded to

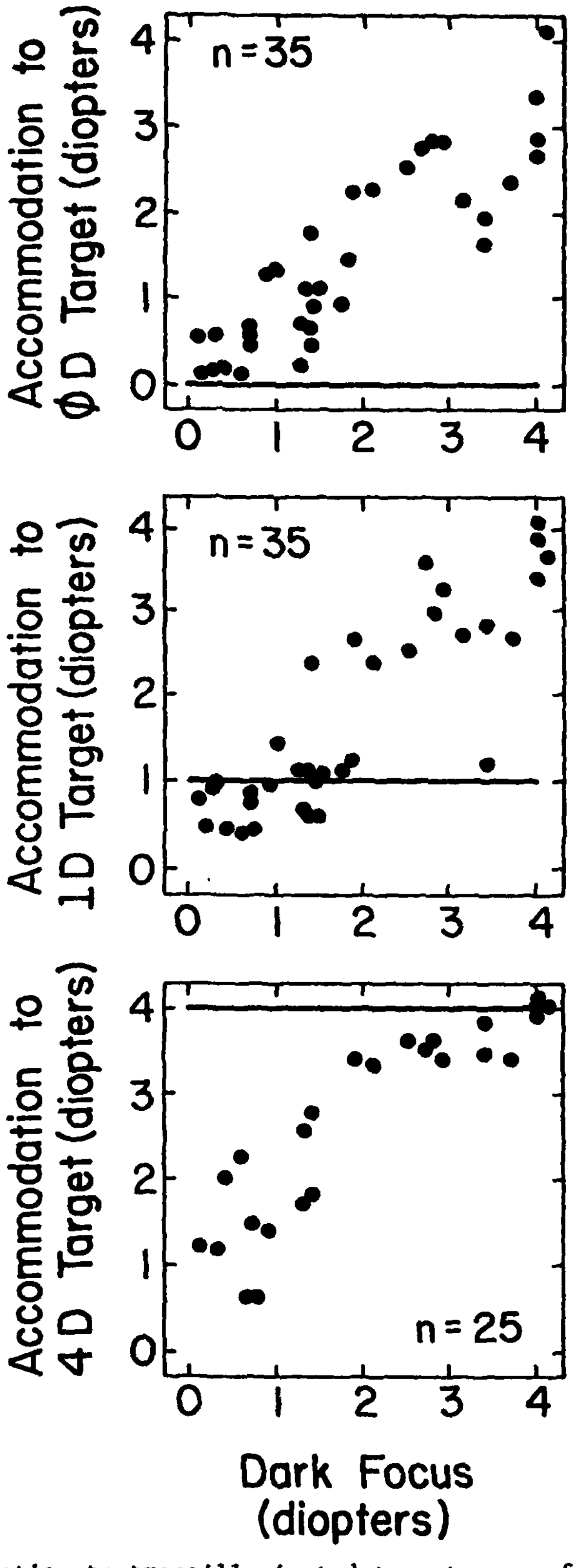

Figure 7. Accommodation to transilluminated targets as a function of the dark focus. Accurate accommodation is represented by the horizontal line.

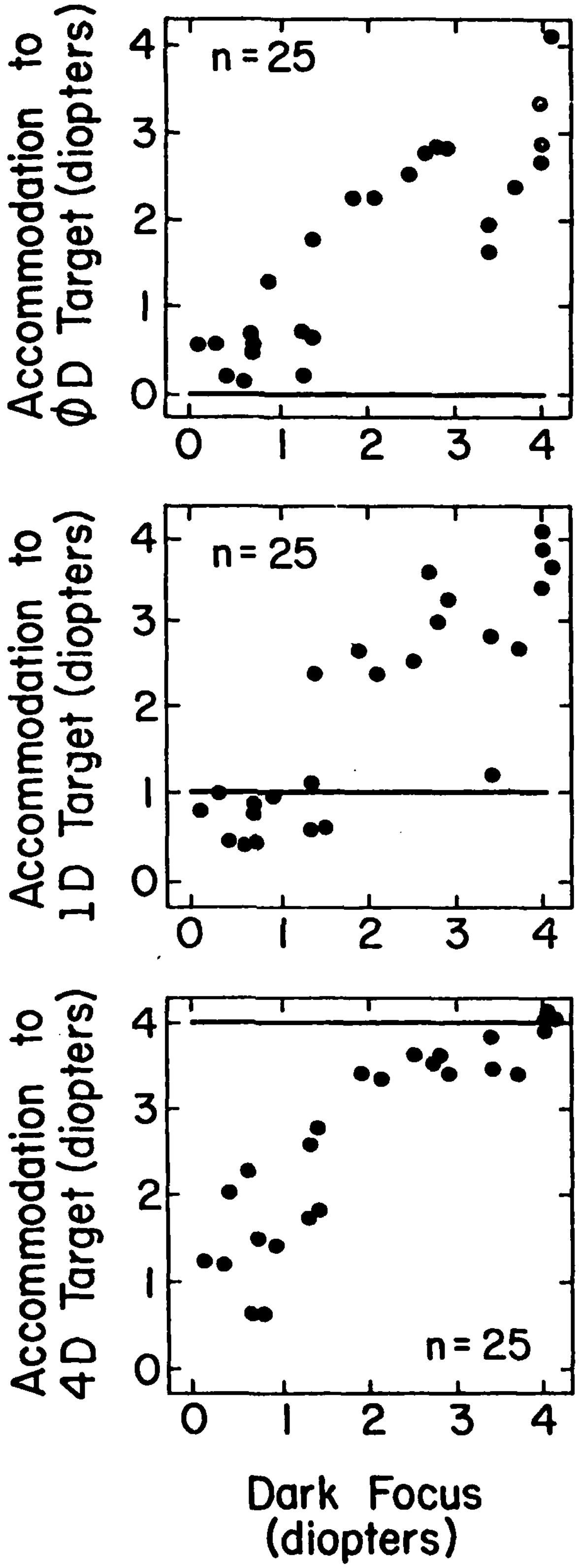

Figure 8. Accommodation to transilluminated targets as a function of the dark focus. Accurate accommodation is represented by the horizontal line. Each point represents a datum for an individual who observed in all three situations.

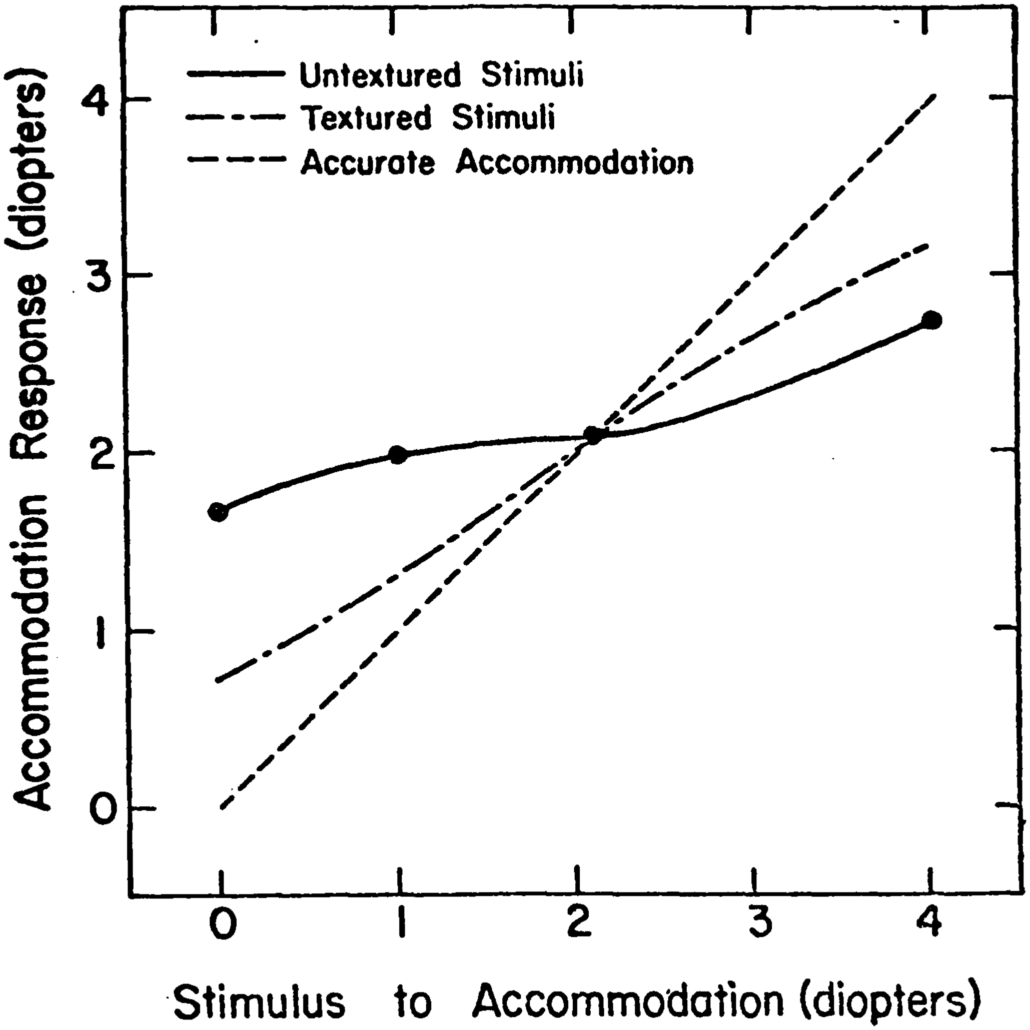

Figure 9. Hypothetical curve derived from lead-lag hypothesis fitted to empirical data. Cross over at dark focus is typical. (Generalized data curve after Toates, 1972)

by others. The relatively low stimulus value associated with the current stimuli (simple lighted discs in a dark surround) appears to result in a larger proportional error of accommodation. The data of Johnson parallel this finding wherein reductions in luminance resulted in increasingly larger proportions of error until, at the lowest luminance, a fixed focus equal to the dark focus characterizes the response. Likewise, Charman and Tucker (1978) indicate that accommodative accuracy is a function of object form. They report accommodation to be quite inaccurate while viewing low frequency (≤ 4 cycles/degree) sinusoidal gratings. Additionally, single frequency targets generally resulted in less accurate accommodation than wide band targets (e.g., Snellen letters) containing both high-and low-frequency components, particularly at the limits of the stimulus range.

In addition to theoretical considerations, the present findings are potentially important for a variety of applied visual problems. For example, data in Figure 9 imply that, the further a stimulus is from an individual's resting position, the higher in stimulus value (as yet an unquantified variable) that object must be to insure even reasonably accurate accommodation. The possibility of quantifying stimulus values of various objects or displays by optically varying the distance to the object bears potential for further work.

As stimuli become less textured within a decreasingly textured visual surround, and as illumination is reduced, accommodation becomes increasingly inaccurate. The limiting value for a particular observer is related, if not identical, to that individual's dark focus. The implications of this finding for vehicle operation under suboptimal visual conditions are manifold. As accommodation decreases in accuracy, perception of size and distance may be affected. Recent evidence (Iavecchia, et al.) suggests that inappropriate near accommodation results in reductions of the apparent size of an object. Conversely, decreased refractive power results in increased apparent size.

Although the evidence from Iavecchia, et al. was applied toward an explanation of the moon illusion, their data dovetail neatly with the present finding. Accommodation to a disc ("moon") presented against an empty sky was very similar to the dark-focus data collected from those observers. Retreating to near accommodation would cause things to appear smaller and farther away (Roscoe, Olzak, and Randle, 1976; Ohwaki, 1955). Perception of objects, such as tail lights while driving, as being relatively more distant could lead to longer latencies for responding with attendant negative consequences. Similarly accurate perception of size and distance is critical for flight.

When illumination is reduced, accommodation has been shown to be inaccurate. Likewise, when the relevant stimuli have lowered stimulus value, accommodation is inaccurate. Under circumstances in which either or both effects are operating at a maximum, accommodation approaches a fixed value that is essentially identical to the dark focus. Improved design of relevant stimuli, e.g., tail lights on cars, runway approach lighting, etc., may increase stimulus value and thereby improve the accuracy of accommodation. Increased visual texture in the surround may also alleviate some of the inaccuracy of accommodation. Such measures would include changes in highway markings and improved runway lighting well beyond current conceptions.

Post, Owens, Owens, and Leibowitz (1979) have demonstrated the possibility for optimizing visual search and detection performance through optical correction. These corrections were based on the dark focus, with full dark-focus correction yielding the largest improvements for observers, particularly so for those with relatively near dark-focus distances. These results were appropriate to the empty visual field. When texture is increased, such as would be encountered in typical night-driving situations, Owens and Leibowitz (1976) found that one half the distance between the dark focus and optical infinity was the most appropriate correction. Apparently the accommodative response is a compromise between stimulus distance and the dark focus, but the final response is also dependent on the spatial characteristics of the available stimuli.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Recent research employing the laser optometer has shown that accommodation is notably inaccurate with reduced illumination, textural cue removal, or small aperture viewing. These situational ametropias are most plausibly and parsimoniously explained as a passive return to an intermediate resting position for accommodation, operationally defined as the dark focus. Although, for any individual, large correlations exist among these ametropias, statistically reliable differences occur among them as well. A series of experiments show that a portion of the differences may be due to chromatic aberration. The dark focus is the major

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determinant of the accommodative response; under steady-state conditions the response is a compromise between stimulus and dark focus distances. Spatial characteristics of the stimuli also appear to be important factors in determining this compromise distance of accommodation.

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